Robotics: Robot

- In ISO 8373, the International Organization for Standardization defines a robot as “an automatically controlled, reprogrammable, multipurpose manipulator with three or more axes.”
- The Robot Institute of America designates a robot as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks.”.
- Robots has demonstrated to play soccer, operate switches, turn doorknobs, and climb stairs, various industrial parts such as welding and spray-painting of automobile bodies, and inspection of products.
- A properly designed robot is truly a mechatronics system.
- The performance of a robotic manipulator depends considerable on the way the manipulator is controlled, and this has a direct impact on the overall performance of the manufacturing system.

Robotics: Robot

- A robot can be interpreted as a control system,
  - Its basics functional components are the structural skeleton of the robot
  - The actuator system which drives the robot
  - The sensor system which measures signals for performance monitoring, task learning and playback, and for control
  - The signal modification system for functions such as signal conversion, filtering, amplification, modulation and demodulation
  - The direct digital controller which generates drive signals for the actuator system so as to reduce response error.
  - Higher level tasks such as path planning, activity coordination and supervisory control have to be treated as well within the overall control system.
- The aim of the robot control system is to guide the robot end-point with respect to the desired trajectory determined by the user and with respect to information received from the sensors.

Robotics: Robot

- The Czech playwright Karel Capek originated the term robot in his 1920 play "R.U.R." It was derived from the Czechoslovakian word robota or robotnik which means slave, servant, or forced labor. In the play, machine workers overthrow their human creators when a scientist gives them emotions.
- The Czech word *robotnik* refers to a peasant or serf, while *robota* means drudgery or servitude.

Motivating factors for the use of Robot

The following are the factors which vouch for the introduction of robotic systems to the industrial world

- Improved quality of products, and Lesser preparation time
- Lower rejects and less waste than labour intensive production
- Higher flexibility of product type and variation
- Skilled labour shortage
- Constant demand for improvement of quality, and Pressure to increase production
- Hazardous environment for humans
- Repetitive work cycle
- Difficult handling for humans

Robotics

- The word 'robotics' was first used in Runaround, a short story published in 1942, by Isaac Asimov (born Jan. 2, 1920, died Apr. 6, 1992).
- Asimov proposed the following "Laws of Robotics":

Zeroth Law:

A robot may not injure humanity, or, through inaction, allow humanity to come to harm.

First Law:

A robot may not injure a human being, or, through inaction, allow a human being to come to harm, unless this would violate a higher order law.

Second Law:

A robot must obey the orders given to it by human beings, except where such orders would conflict with a higher order law.

Third Law:

A robot must protect its own existence, as long as such protection does not conflict with a higher order law.

Robot manipulator: structure

- The robot manipulator consists of a
  - robot arm,
  - wrist, and
  - gripper.
- The task of the robot manipulator is to place an object grasped by the gripper into an arbitrary pose.
- In this way also the industrial robot needs to have six degrees of freedom.
- The segments of the robot arm are relatively long.
- The task of the robot arm is to provide the desired position of the robot end point.
- The segments of the robot wrist are rather short.
- The task of the robot wrist is to enable the required orientation of the object grasped by the robot gripper.

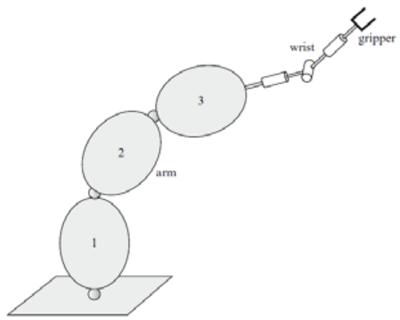


Figure 8.1 Robot manipulator

Robot arm

- The robot arm is a serial chain of three rigid bodies called robot segments.
- Two neighbor segments of a robot manipulator are connected through a robot joint.
- The joint decreases the number of degrees of freedom which occur between two neighbor segments.
- The robot joints have only one degree of freedom and are either translational or rotational.
- The axes of two neighboring joints are either parallel or perpendicular.
- As the robot arm has only three degrees of freedom, there exist a limited number of possible combinations resulting all together in 36 different structures of robot arms.
- Among them only 12 are functionally different.
- On the market we find 5 commercially available structures of robot arms: anthropomorphic, spherical, SCARA, cylindrical, and cartesian.

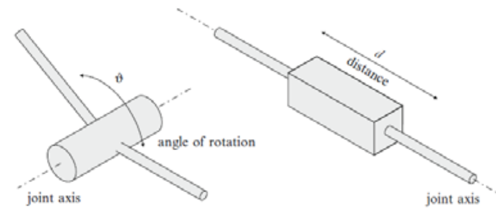


Figure 8.2 Rotational (left) and translational (right) robot joint

Robot arm

- The anthropomorphic robot arm (Figure 8.3) has all three joints of the rotational type (RRR).
- Among the robot arms it resembles the human arm to the largest extent.
- The second joint axis is perpendicular to the first one, while the third joint axis is parallel to the second one.
- The workspace of the anthropomorphic robot arm, encompassing all the points that can be reached by the robot end point, has a spherical shape.

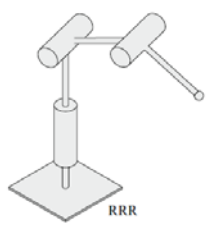


Figure 8.3 Anthropomorphic robot arm

Robot arm

- The spherical robot arm (Figure 8.4) has two rotational and one translational degree of freedom (RRT).
- The second joint axis is perpendicular to the first one and the third axis is perpendicular to the second one.
- The workspace of the robot arm has a spherical shape as in the case of the anthropomorphic robot arm.

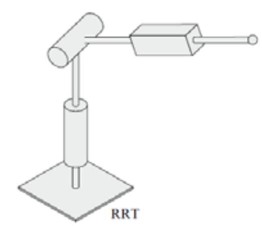


Figure 8.4 Spherical robot arm

Robot arm

- The SCARA (Selective Compliant Articulated Robot for Assembly) robot arm appeared relatively late in the development of industrial robotics (Figure 8.5).
- It is predominantly aimed for industrial processes of assembly.
- Two joints are rotational and one is translational (RRT).
- The axes of all three joints are parallel.
- The workspace of SCARA robot arm is of cylindrical shape.

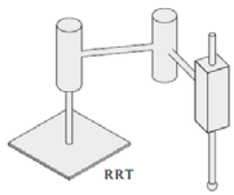


Figure 8.5 SCARA robot arm

Robot arm

- The cylindrical shape of the workspace is even more evident with the cylindrical robot arm (Figure 8.6).
- This robot has one rotational and two translational degrees of freedom (RTT).
- The axis of the second joint is parallel to the first axis, while the third joint axis is perpendicular to the second one

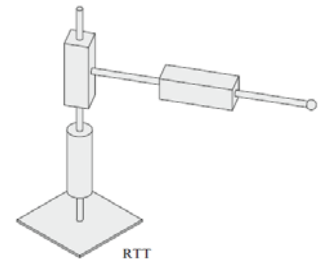


Figure 8.6 Cylindrical robot arm

Robot arm

- The cartesian robot arm (Figure 8.7) has all three joints of the translational type (TTT).
- The joint axes are perpendicular one to another.
- Cartesian robot arms are known for high accuracy, while the special structure of gantry robots is suitable for manipulation of heavy objects.
- The workspace of the cartesian robot arm is a prism.

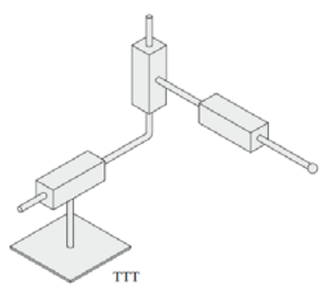


Figure 8.7 Cartesian robot arm

Robot Classification

Based on kinematic structure

- Six degree of freedom (DOF) are required for a robot to arbitrarily position and orient an object in the 3D space.
- It is customary to assign three of these DOF to the wrist that manipulates the end effector (hand/gripper),
  - remaining three to the arm of the robot.
- The sequence of rotary/revolute (R) joints and rectilinear/ prismatic (T) joints are employed in the arm structure will classify a robot as shown in different types of robot arm.

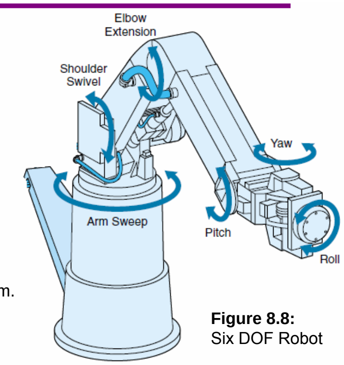


Figure 8.8: Six DOF Robot

Based on actuator type

e.g. hydraulic, dc/ac servo, stepper motor.

Based on transmission type

e.g. geared, direct-drive, harmonic-drive, timing-belt, chain and sprocket, and traction-drive or friction-drive

Based on capacity and accuracy

e.g. heavy duty industrial robots and microminiaturized finger robots.

Based on mobility: e.g. mobile robot and AGV (automated guided vehicle)

Robotic tasks

Robotics tasks can be grouped broadly into

(1) gross manipulation tasks:

- Control of the motion trajectory of the robot end effector is directly applicable to tasks of this category.
- e.g. seam tracking in arc welding, spray painting, contour cutting (laser and water jet) and joining (e.g. gluing, sewing, ultrasonic and laser merging), and contour inspection (e.g. ultrasonic, electromagnetic and optical).

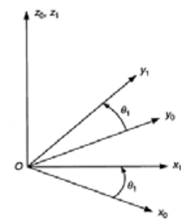
(2) Fine manipulation tasks:

- Force and tactile considerations are generally crucial to tasks in the second category.
- e.g. Part assembly, robotic surgery, machining, forging, and engraving are examples of fine manipulation tasks.

- It is intuitively clear that gross manipulation can be accomplished through motion control.

Robot kinematics

- It is important to know the position and orientation (geometric configuration) of a robot, along with velocities and accelerations of the robot components (links) in order to monitor and properly control the robot.
- Determination of these geometric configuration parameters and their derivatives is the kinematics problem of a robot.
- Coordinate transformation plays an important role in this problem.



$$R_1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Robot kinematics: D-H notation

- Joint i joins link i-1 with link i
- Frame i, which is the body frame of link i, has its z axis located at joint i+1
- If the joint is revolute, then the joint rotation is about the z axis
- If the joint is prismatic, the joint translation us along the z axis
- It is seen from the Figure that frame i can be obtained by transforming frame i-1 as follows:

1. rotate frame i-1 by an angle of θ_i about the z axis.
2. Translate the new frame through d_i along z axis.
3. Translate the new frame through a_i along the new x axis.
4. Rotate the new frame by an angle α_i about the current x axis.

Note: All the movements are carried out in the positive Sense of a right-handed Cartesian frame.

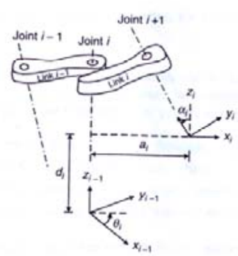


Figure 8.9: Denavit-Hartenberg notation

Robot kinematics: D-H notation

- Joint i joins link i-1 with link i
- Frame i, which is the body frame of link i, has its z axis located at joint i+1
- If the joint is revolute, then the joint rotation is about the z axis
- If the joint is prismatic, the joint translation us along the z axis
- It is seen from the Figure that frame i can be obtained by transforming frame i-1 as follows:

1. rotate frame i-1 through

$$A_i = \begin{pmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & \cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Robot kinematics: D-H notation

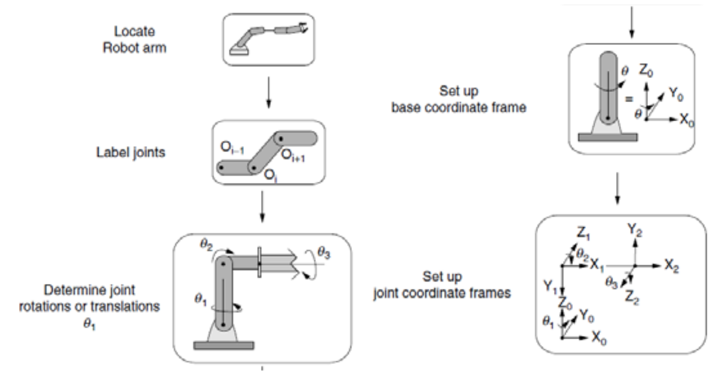
In In a robot manipulator, there are commonly two types of joints: revolute and prismatic.

The revolute joint allows for rotation between two links about an axis, and the prismatic joint allows for translation (sliding) motion along an axis.

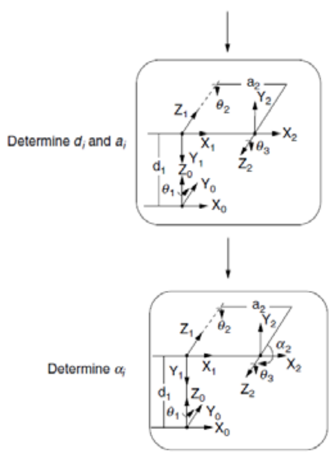
In a revolute joint, the link offset *d* is a constant while the joint angle *θ* is a variable, and in a prismatic joint, the link offset *d* is variable and the joint angle *θ* is normally zero.

The link length *ai* and the twist angle *αi* are determined by the geometry of the manipulator and are therefore constant values.

Robot kinematics: D-H notation: Flowchart



Robot kinematics: D-H notation

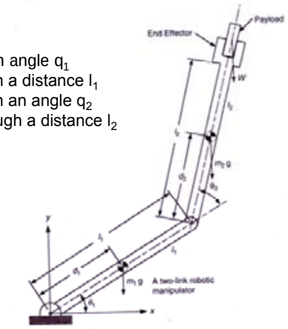


Axis Number	Twist angle α_i	Link length a_i	Link offset d_i	Joint angle θ_i
1	α_1	a_1	d_1	θ_1
2	α_2	a_2	d_2	θ_2
⋮				
⋮				
n	α_n	a_n	d_n	θ_n

Robot kinematics: Example-1

Consider the 2 DOF, revolute manipulator sketched in the Figure shown. Suppose that a body frame for the end effector may be defined using the following transformations, starting from the base frame (x, y, z) that is shown in the figure:

Step 1: rotate the base frame about the z axis through an angle q_1
Step 2: move the new frame along the new x axis through a distance l_1
Step 3: rotate the resulting frame about the z axis through an angle q_2
Step 4: move the latest frame along the latest x axis through a distance l_2



a. Give the 4*4 homogeneous transformations corresponding to each of the steps 1 through 4 above.

b. Multiply the transformations in part (a) in the proper order to describe the kinematics of the manipulator (i.e. to express the end effector frame with respect to the base frame).

c. From part (b) obtain the coordinates of the origin of the end effector frame, with respect to, and expressed in, the base frame.

Robot kinematics: Example-1: solution

a. It is seen that the transformation matrices are:

$$A_1 = \begin{bmatrix} \cos q_1 & -\sin q_1 & 0 & 0 \\ \sin q_1 & \cos q_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 1 & 0 & 0 & l_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} \cos q_2 & -\sin q_2 & 0 & 0 \\ \sin q_2 & \cos q_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_4 = \begin{bmatrix} 1 & 0 & 0 & l_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

b. The overall transformation matrix is

$A = A_1 A_2 A_3 A_4$

on multiplication and simplification we get:

$$A = \begin{bmatrix} \cos(q_1+q_2) & -\sin(q_1+q_2) & 0 & l_2\cos(q_1+q_2)+l_1\cos q_1 \\ \sin(q_1+q_2) & \cos(q_1+q_2) & 0 & l_2\sin(q_1+q_2)+l_1\sin q_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

c. The first three elements of the last (4th) column of A, as obtained in Part (c), give the origin of the end effector frame.

NOTE: We have used the following trigonometric identities:

$\cos(q1+q2)=\cos q1 \cos q2-\sin q1 \sin q2$

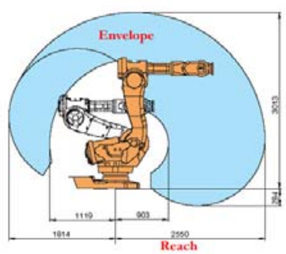
$\sin(q1+q2)=\sin q1 \cos q2+\cos q1 \sin q2$

Robot Specifications

- **Accuracy**: How close does the robot get to the desired point?
- **Repeatability**: The ability of a robot to return repeatedly to a given position. It is the ability of a robotic system or mechanism to repeat the same motion or achieve the same position. Repeatability is a measure of the error or variability when repeatedly reaching for a single position. Repeatability is often smaller than accuracy.
- **Degree of Freedom (DOF):** Each joint or axis on the robot introduces a degree of freedom. Each DOF can be a slider, rotary, or other type of actuator. The number of DOF that a manipulator possesses thus is the number of independent ways in which a robot arm can move. An industrial robot typically have 5 or 6 degrees of freedom.
  - 3 of the degrees of freedom allow positioning in 3D space (X, Y, Z), while the other 2 or 3 are used for orientation of the end effector (yaw, pitch and roll).
  - 6 degrees of freedom are enough to allow the robot to reach all positions and orientations in 3D space.
  - 5 DOF requires a restriction to 2D space, or else it limits orientations. 5 DOF robots are commonly used for handling tools such as arc welders.

Robot Specifications

- **Resolution**: The smallest increment of motion or distance that can be detected or controlled by the robotic control system.
- **Envelope**: A three-dimensional shape that defines the boundaries that the robot manipulator can reach; also known as reach envelope.
  - **Maximum envelope**: the envelope that encompasses the maximum designed movements of all robot parts, including the end effector, workpiece and attachments.
  - **Restricted envelope** is that portion of the maximum envelope which a robot is restricted by limiting devices.
  - **Operating envelope**: the restricted envelope that is used by the robot while performing its programmed motions.
- **Reach**: The maximum horizontal distance from the center of the robot base to the end of its wrist.



Robot Specifications

- **Maximum Speed**: A robot moving at full extension with all joints moving simultaneously in complimentary directions at full speed.
  - The maximum speed is the theoretical values which does not consider under loading condition.
- **Payload**: The maximum payload is the amount of weight carried by the robot manipulator at reduced speed while maintaining rated precision.
  - Nominal payload is measured at maximum speed while maintaining rated precision. These ratings are highly dependent on the size and shape of the payload due to variation in inertia.
- http://www.robotmatrix.org

Robot: drive systems

- Robotic mechanisms are actuated by the following drive systems:

1. Pneumatic drive:
   pressurized air is supplied through lines to cylinders, causing air pressure to be transformed into mechanical work.

2. Hydraulic drive:
   pressurized fluid entering into cylinders causes the cylinder to extend or retract.

3. Electric drive:
   electric drive systems either use AC or DC electric motors.
   Motors are connected to the manipulator's axes through gear reduction mechanisms to develop necessary torque for the robot to lift heavy payloads.

Robot: applications

Robots in medical

- The growth of medical robotics since the mid-1980s has been striking.
- From a few initial efforts in stereotactic brain surgery, orthopaedics, endoscopic surgery, microsurgery, and other areas, the field has expanded to include commercially marketed, clinically deployed systems, and a robust and exponentially expanding research community.

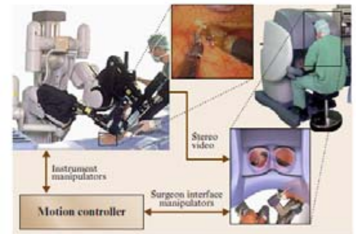


Figure .. The daVinci telesurgical robot extends a surgeon's capabilities by providing the immediacy and dexterity of *open* surgery in a minimally invasive surgical environment. (Photos: Intuitive Surgical, Sunnyvale)

Robot: applications

Robots in agriculture

- In agriculture and forestry, robotics has made a substantial impact.
- Farmers are conscious of their need for automatic vehicle guidance to minimize damage to the growing zone of their soil.
- Automatic sensing, handling, and processing of produce are now commonplace, while there is substantial instrumentation and mechanization of livestock procedures.
- In forestry, legged harvesters have not yet seen great success in their application, but the automation of trimming and forwarding with simultaneous localization and mapping techniques will change the industry in the future.
- The combination of machine vision with global positioning by satellite (GPS) allows a tractor to follow a row of crops, performing a headland turn at the end of the row.

Figure .. Walking forest harvester prototype by Plustech Ltd., today part of John Deere

Robot: applications

Arial Robots

- *Remote sensing* such as pipeline spotting, powerline monitoring, volcanic sampling, mapping, meteorology, geology, and agriculture, as well as unexploded mine detection.
- *Disaster response* such as chemical sensing, flood monitoring, and wildfire management.
- *Surveillance* such as law enforcement, traffic monitoring, coastal and maritime patrol, and border patrols.
- *Search and rescue* in low-density or hard-to-reach areas.
- *Transportation* including small and large cargo transport, and possibly passenger transport.
- *Communications* as permanent or ad hoc communication relays for voice and data transmission, as well as broadcast units for television or radio.
- *Payload delivery* e.g., firefighting or crop dusting.
- *Image acquisition* for cinematography and real-time entertainment.

Figure .. QH-50 DASH unmanned helicopter on final approach (US Navy)

Robot: applications

Search and rescue Robots

- Rescue robots serve as extensions of responders into a disaster, providing real-time video and other sensory data about the situation.
- As of 2006, they have been used in four disasters in the United States (World Trade Center, and hurricanes Katrina, Rita, and Wilma), where they were still viewed as a novelty.
- In local incidents. For example, several fire rescue departments in Japan and the United States routinely use small underwater robots for water-based search and recovery, a ground robot has been used for a mine explosion in the United States, and interest in the use of aerial vehicles for wilderness search and rescue is growing.

Figure.. Man-packable UAVs used to search portions of Mississippi during the hurricane Katrina response: an iSENSYS IP3 rotary-wing UAV (courtesy of CRASAR)

Robot: applications

Space Robots

- In the space community, any unmanned spacecraft can be called a robotic spacecraft.
- *space robots* are considered to be more capable devices that can facilitate manipulation, assembling, or servicing functions in orbit as assistants to astronauts, or to extend the areas and abilities of exploration on remote planets as surrogates for human explorers.

Figure .. The Mars exploration rovers, spirit and opportunity, with a manipulator arm in front

Robot: applications

Intelligent vehicle

- An important field of application of robotics has emerged in the last 20–25 years which is centered on the automobile, named *intelligent vehicles*.
- The automobile has been one of the most important products of the 20th century.
- An intelligent vehicle is defined as a vehicle enhanced with perception, reasoning, and actuating devices that enable the automation of driving tasks such as
  - safe lane following,
  - obstacle avoidance,
  - overtaking slower traffic,
  - following the vehicle ahead,
  - assessing and avoiding dangerous situations, and determining the route.
- The overall motivation of building intelligent vehicles has been to make motoring safer, and more convenient and efficient.

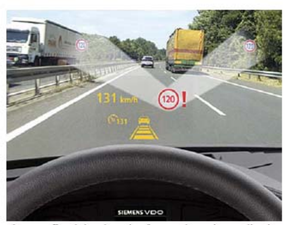
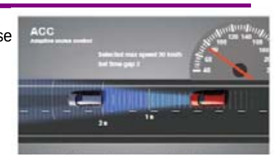


Fig. 51.7 Road sign detection for speed warning application.

Robot: applications: Intelligent vehicle

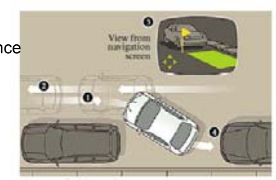
Lane detection

Advanced cruise control (ACC)



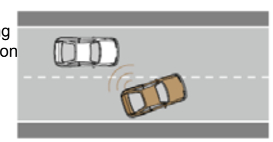
Vehicle detection – lane and range position

Parking assistance



Blind-spot detection

Lane changing – side detection



Robot: applications

Under water Robots

- The offshore oil and gas industry relies heavily on UWR for installation, inspection, and servicing of platforms, pipelines, and subsea production facilities.
- search for oil and gas goes deeper,
- seafloor studies
- forensic investigations of modern shipwrecks to determine the cause of sinking, archaeology, and salvage.

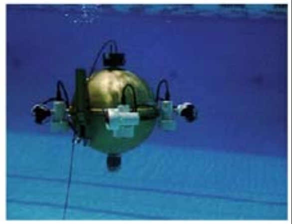


Figure.. The fully actuated AUV ODIN (courtesy of the Autonomous Systems Laboratory, University of Hawaii, http://www.eng.hawaii.edu/□asl/) AUV-Automated Underwater Vehicle

Robot grippers

- Mechanical grippers:- consisting of two or more fingers that can be actuated by the robot controller to open and close to grasp the work-piece.
- Vacuum grippers:- such cups are used to hold flat objects.
- Magnetized devices:- for holding ferrous work-pieces.
- Adhesive devices:- where adhesive substances are used to hold flexible materials like fabric.
- Simple mechanical devices:- such as hooks and scoops.

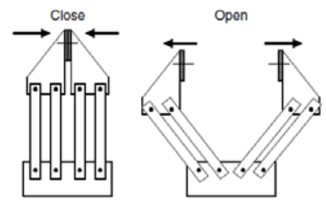
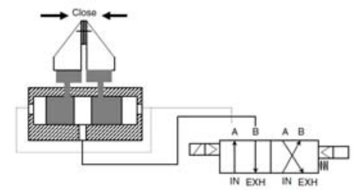
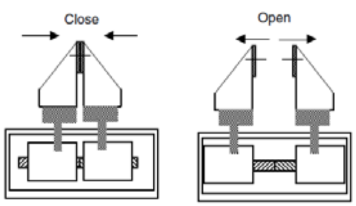


FIGURE Four bar linkages gripper arms.

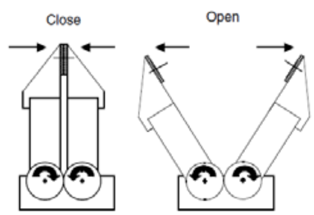


Pneumatic valve connections for safety.

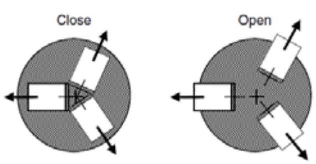
Robot grippers



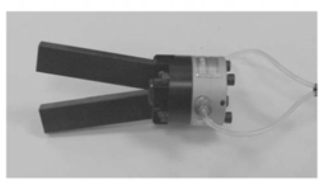
Parallel axes/linear jaws.



Rotating axes/pivoting jaws.



Multi-jaw chuck axes



Rotating axes pneumatic gripper

Robot grippers

Robot sensors

- Important component parts of any robotic system are sensors.
- Here, we distinguish between internal and external sensors.
- Internal sensors assess position and velocity of robot segments and are placed into robotic joints.
- Among external sensors, the most important are the sensor of contact forces and the robot vision sensors.
- The aim of the robot control system is to guide the robot end-point with respect to the desired trajectory determined by the user and with respect to information received from the sensors.